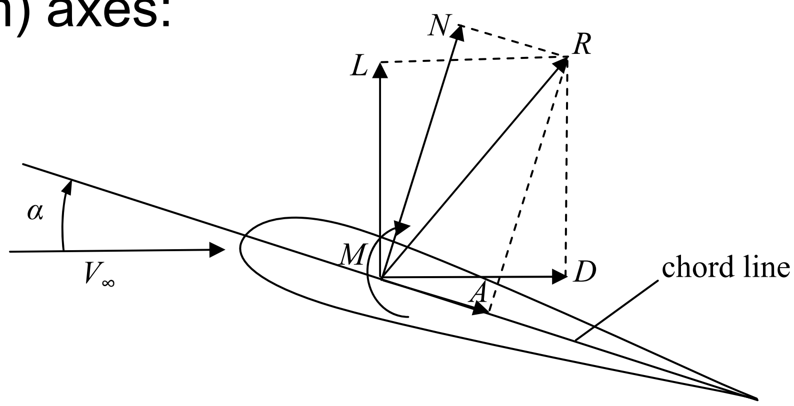
Aerodynamics: Introduction

- Aerodynamics deals with the motion of objects in air. These objects can be airplanes, missiles or road vehicles.
- The Table below summarizes the aspects of vehicle performance directly influenced by aerodynamic design.

Performance	Fuel Economy
	Emissions
	Maximum Speed
	Acceleration
Stability	Directional Stability
	Response to Flow Unsteadiness
	Crosswind Sensitivity
Cooling	Engine
	Transmission
	Brakes
	Condenser
Comfort	Heating, Ventilation and Air Conditioning
	Wind Noise
Visibility	Dirt Accumulation
	Splash and Spray

Aerodynamics: Aerodynamic Forces

• The resultant force, *R*, can be resolved into two components along the wind (freestream) axes:



lift = *L* = component normal to $V\infty$
drag = *D* = component along $V\infty$

or along the body axes axis:

normal force = *N* = component normal to the airfoil chord
axial force = *A* = component along the body chord

• The point at which the resultant force acts is called the *center of pressure*.

• It is convenient sometimes to specify the *aerodynamic center* which is defined as the point at which the aerodynamic moment, *M*, is independent of the angle of attack, α.

Aerodynamics: Aerodynamic Forces

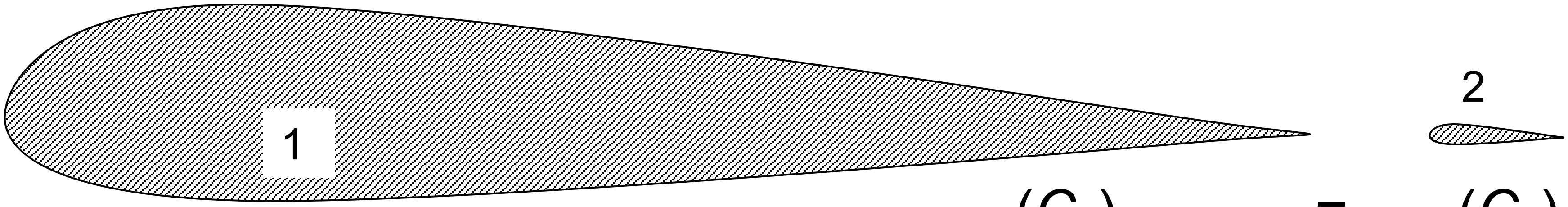
From dimensional analysis, the above coefficients depend on some parameters:

• *Mach number*, M = V_∞ / a where *a* is the speed of sound.

• *Reynolds number*, $Re = \rho V_\infty l / \mu$ where ρ is the air density and μ is the dynamic viscosity of the air.

• *Angle of attack*, α.

• In many practical problems, the lift, drag and moment *coefficients* are identical for geometrically similar bodies at the same Mach and Reynolds number.



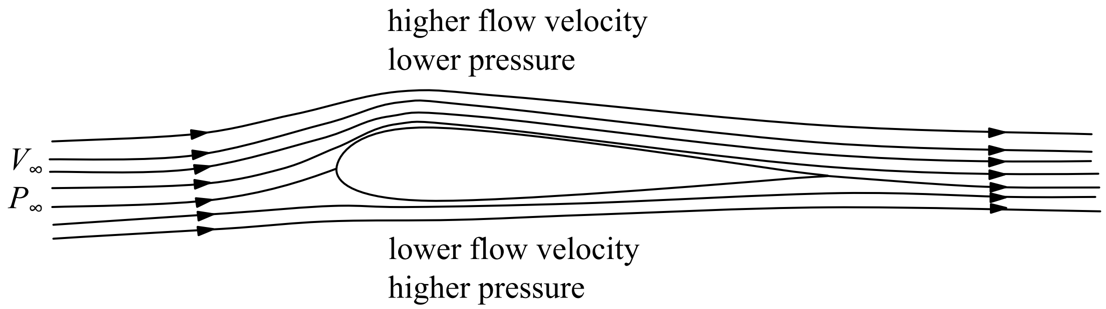
$$(C_L)_1 = (C_L)_2$$

$$(C_D)_1 = (C_D)_2$$

$$(C_M)_1 = (C_M)_2$$

Aerodynamics: Airfoil

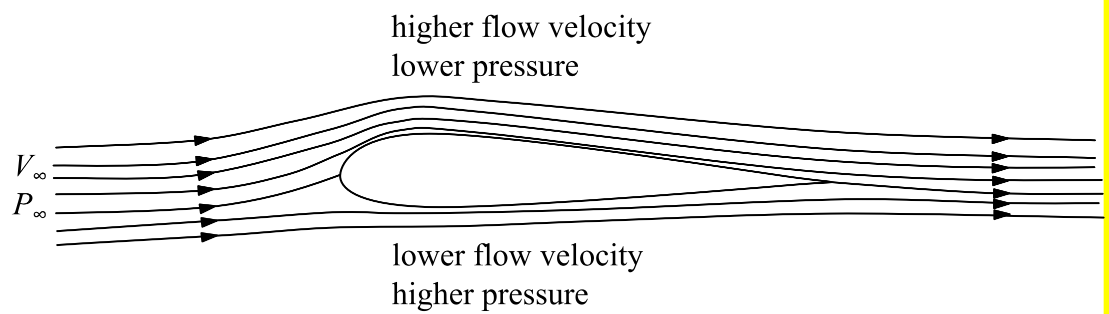
- An *airfoil* is simply a section cut of a wing.
- It is often called infinite wing.
- The flow characteristics around an airfoil are significantly different from those around a wing.
- The flow around the airfoil is two dimensional.



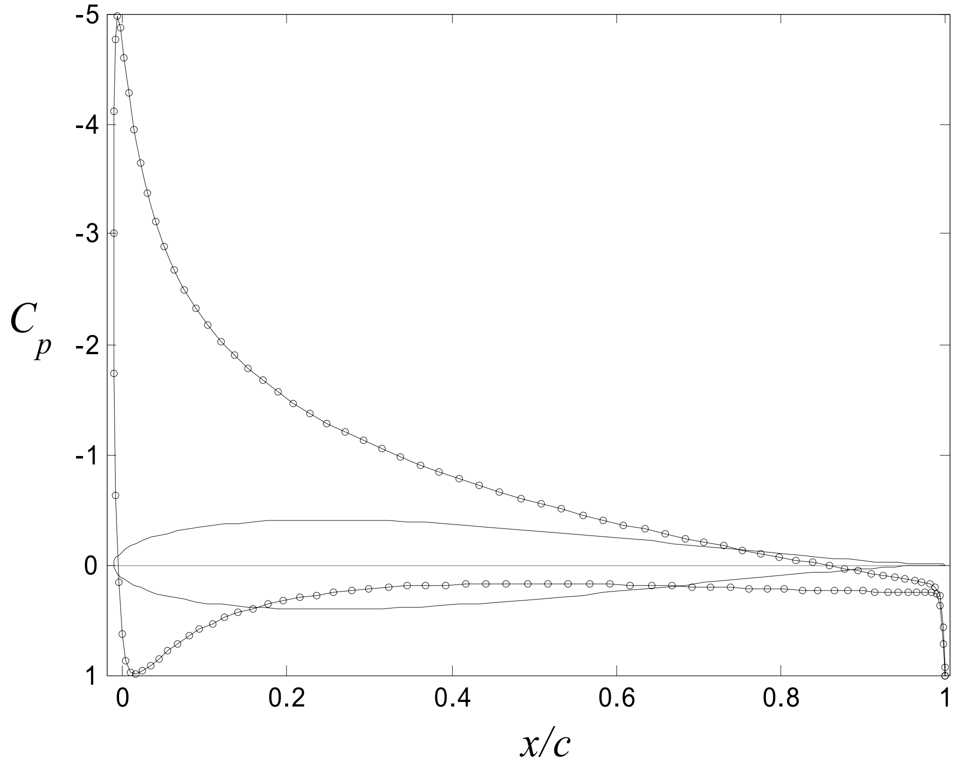
Aerodynamics: Airfoil

- The pressure and velocity fields around the airfoil are related via the *Bernoulli's equation*

$$P_\infty + \frac{1}{2}\rho V_\infty^2 = P + \frac{1}{2}\rho V^2$$



- The pressure distribution over Joukowski airfoil at α = 10º.



- The pressure coefficient is negative (means lower than the freestream pressure, P_∞) over the top surface and positive (higher than the freestream pressure, P_∞) on the bottom surface of the airfoil.

- The net imbalance of pressure distribution produces the lift.

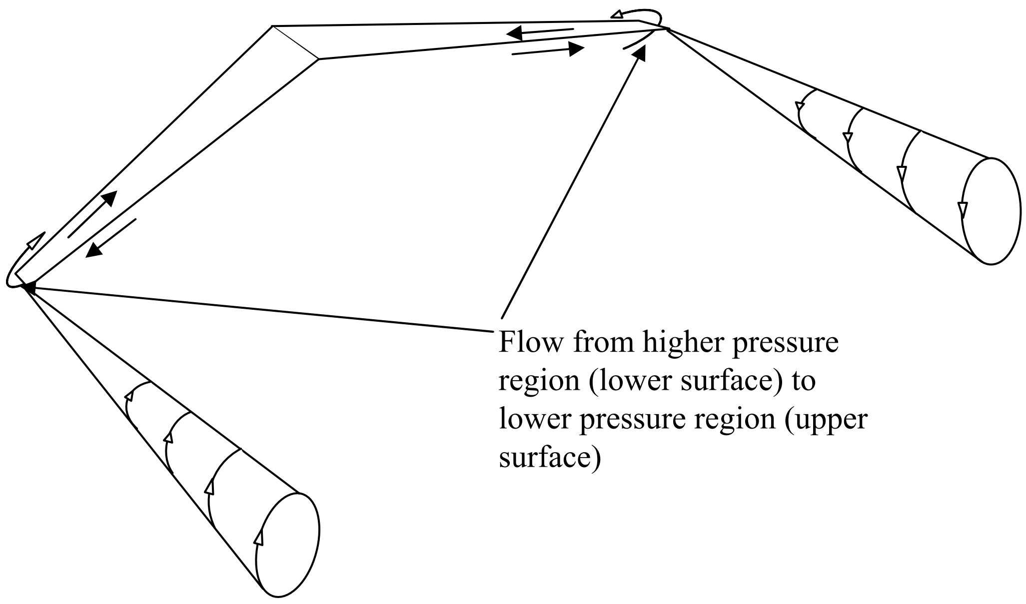
Aerodynamics: Wings

- Often called finite wing

- The flow around a wing is three dimensional; there is a flow in the spanwise direction.

- The mechanism for generating lift is the same as that for the airfoil, a higher pressure on the bottom surface and a lower pressure over the top surface.

- As consequence of the pressure imbalance between the lower and upper surface of the wing, the flow near the wing tips tends to curl around the tips; the flow is forced from the higher pressure region just underneath the wing tips to the lower pressure region on the top of the wing.



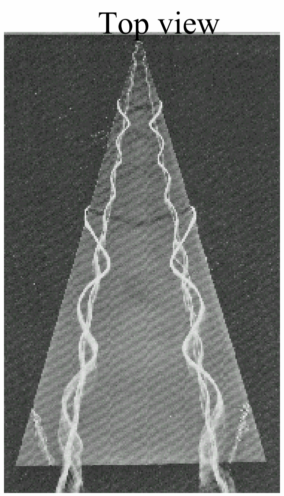
Aerodynamics: Wings

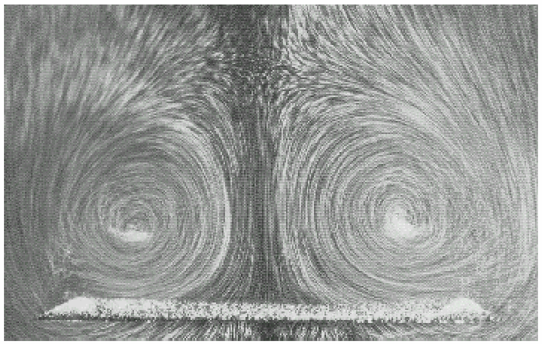
- This causes the flow *underneath* the wing to move along the spanwise direction from the wing root to the tip and the flow *on top* of the wing to move from the wing tip to the root.

- This flow produced a *trailing vortex* at both wing tips that trails downstream of the wing.

- For large airplanes such as the Boeing 747, these vortices are powerful enough to cause light airplanes flying closely behind to go out of control.

- Accidents due to these vortices have occurred and that is one of the reasons for large spacing between aircraft during landing and take-off at airports.





Aerodynamics: Lift and Circulation

• Example of this relation:

flow over a circular cylinder

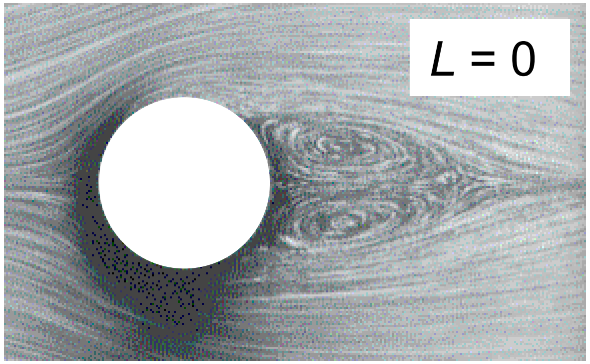
• The flow around non-lifting circular cylinder is symmetric

• Hence one would expect that the pressure distribution over the top and bottom surfaces of the cylinder is also symmetric.

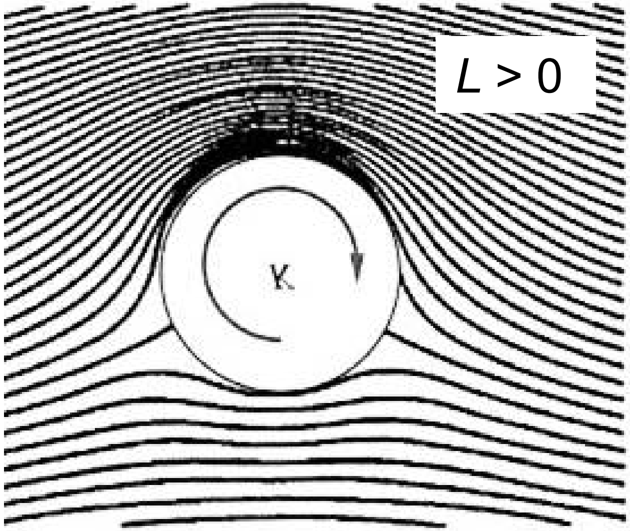
•This results in zero lift for the cylinder.

•However, if the cylinder rotates about its axis, then the flow field is not symmetric any more.

Flow over Non-lifting circular cylinder



Flow over lifting circular cylinder



Aerodynamics: Lift and Circulation

- Why do we have a lift when the cylinder rotates?.

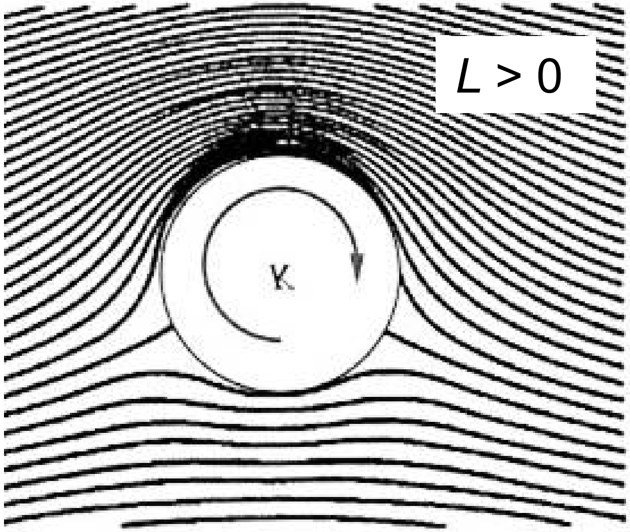
  - When the cylinder rotates, this will increase the flow velocity over the top surface and decrease it on the bottom of the cylinder.

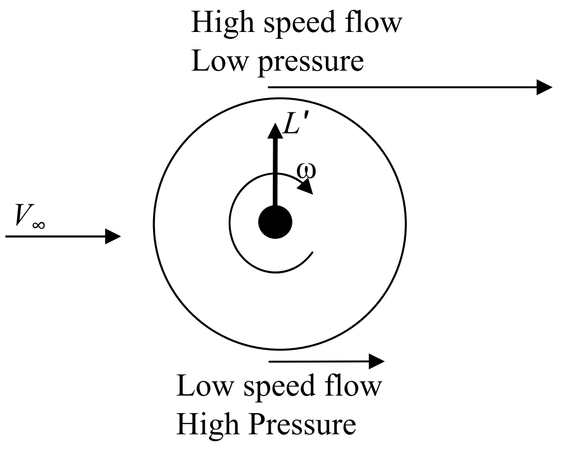
  - As a result, the pressure on the top surface decreases and the pressure on the bottom surface increases (Bernoulli's equation).

$$P_\infty + \frac{1}{2}\rho V_\infty^2 = P + \frac{1}{2}\rho V^2$$

- This net imbalance of pressure will produce a finite lift as sketched in Figure. This is often called Magnus effect.

Flow over lifting circular cylinder

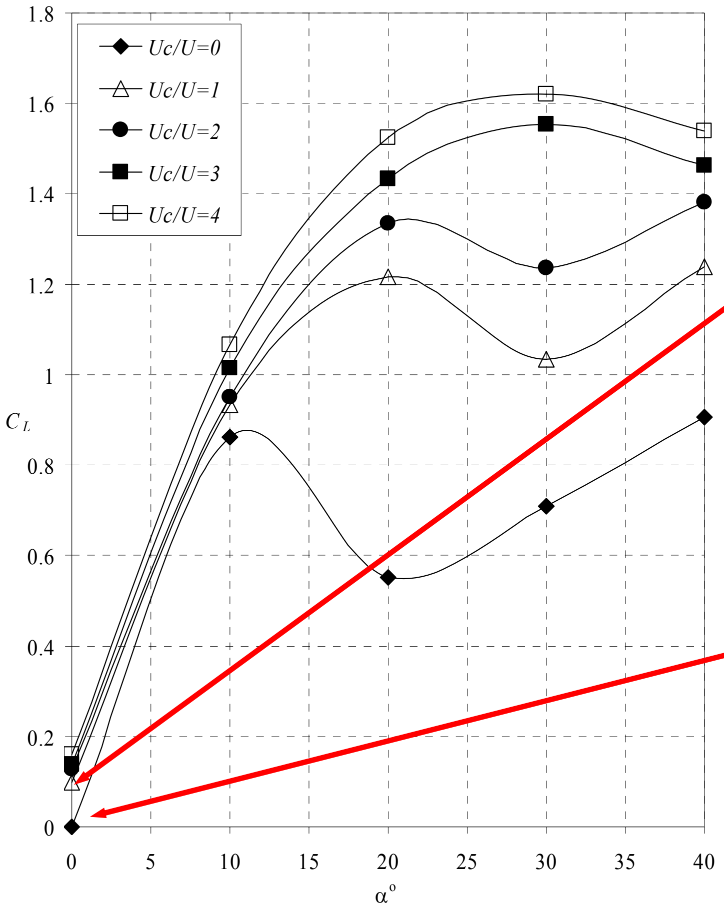




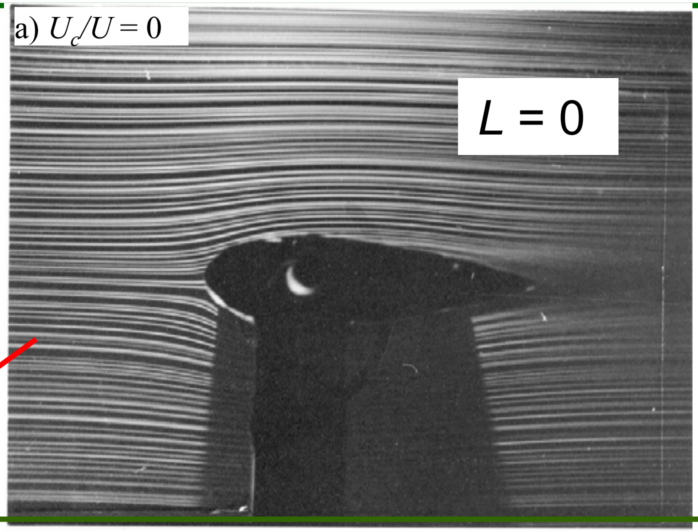
Aerodynamics: Lift and Circulation

- Another Example of this relation:

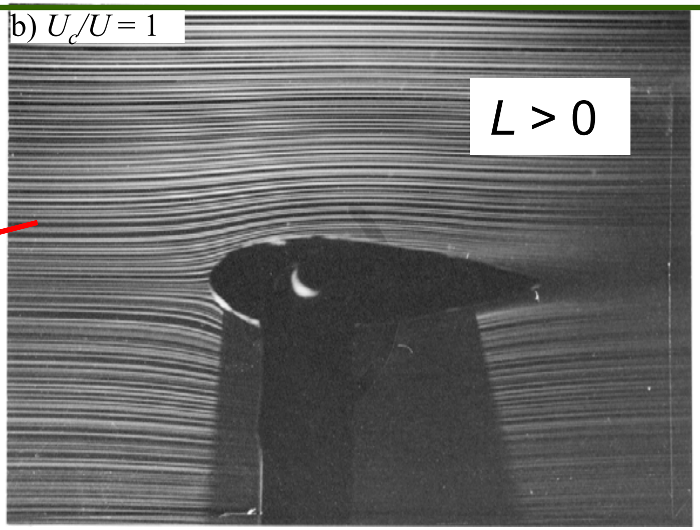
flow over a airfoil with a leading-edge rotating cylinder



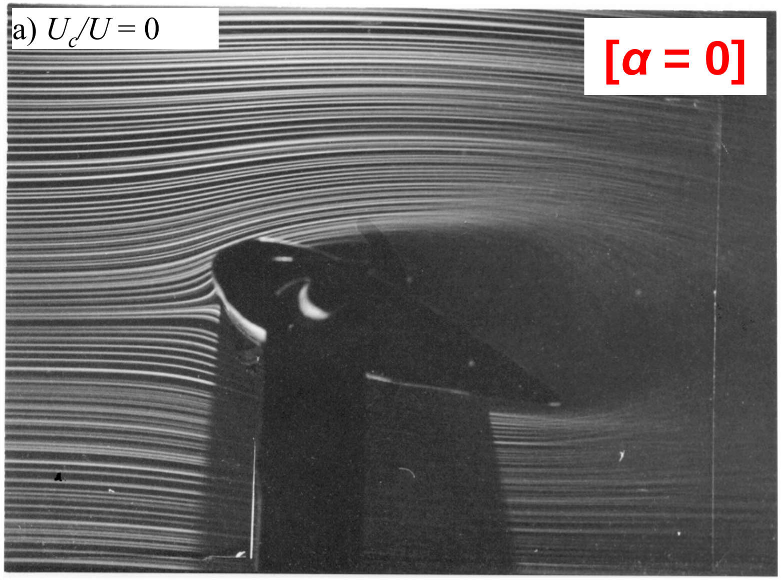
Leading-edge cylinder is off **[α = 0]**

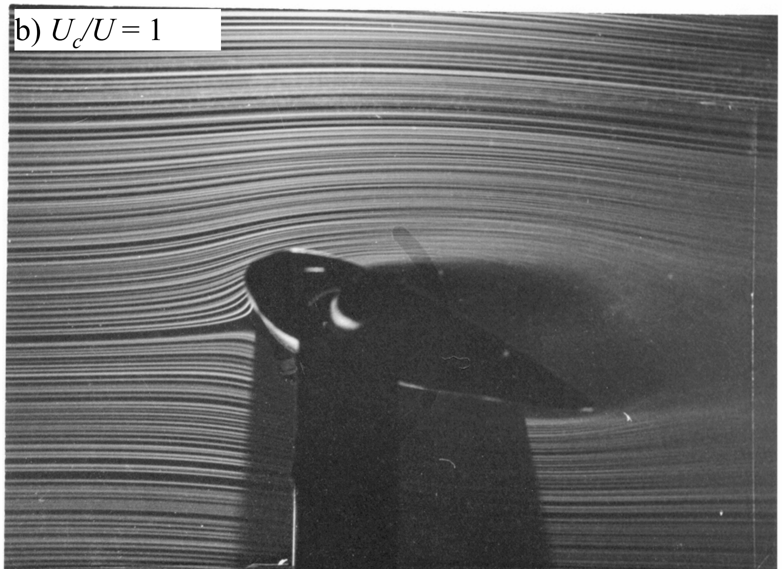


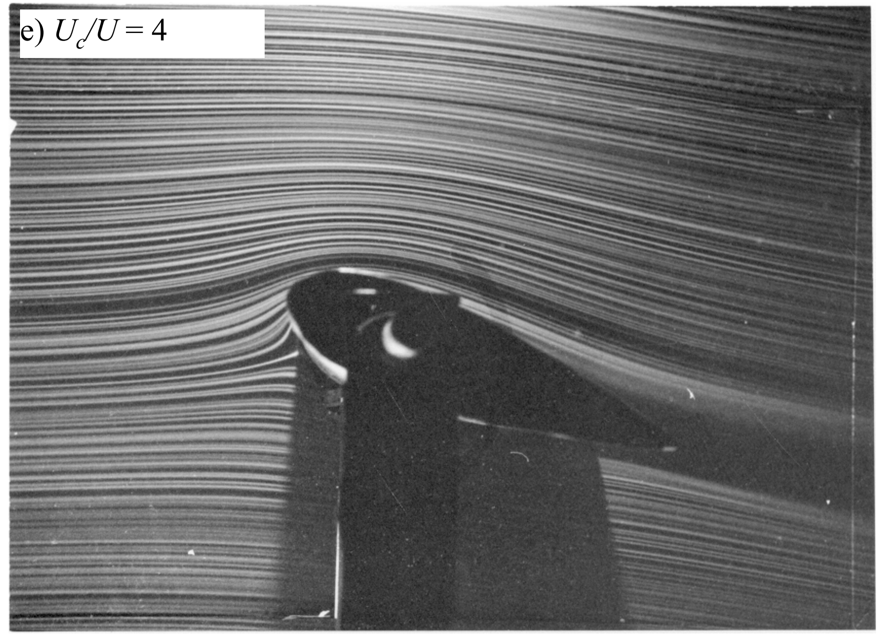
Leading-edge cylinder rotates



Aerodynamics: Lift and Circulation







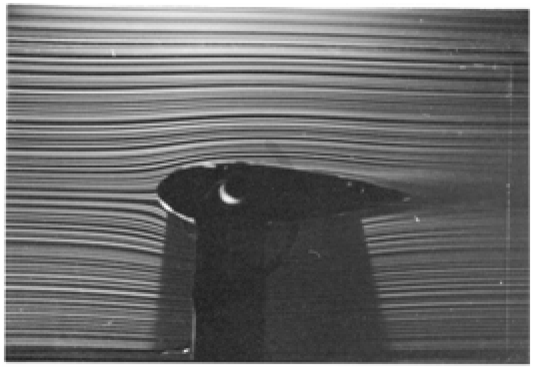
Aerodynamics: Streamlined vs. Bluff body

• Airfoils, flat plate and wings are considered to be streamlined bodies. On the other hand, cylinder, sphere, trucks are bluff bodies.

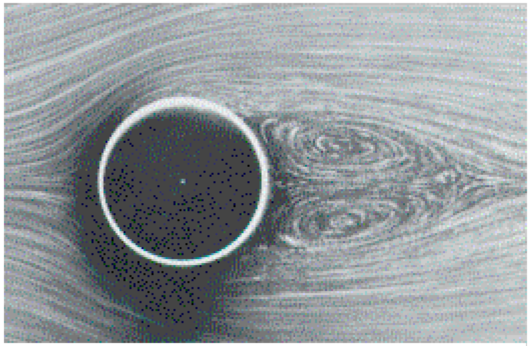
• The flow around streamlined and bluff bodies is significantly different.

• The flow over streamlined body is usually smooth and the wake behind the body is small.

• The flow over bluff body, however, exhibits a large wake downstream the body. This wake is caused by separating flow from the body surface with a low-energy recirculating flow inside the wake as shown in the figure below.

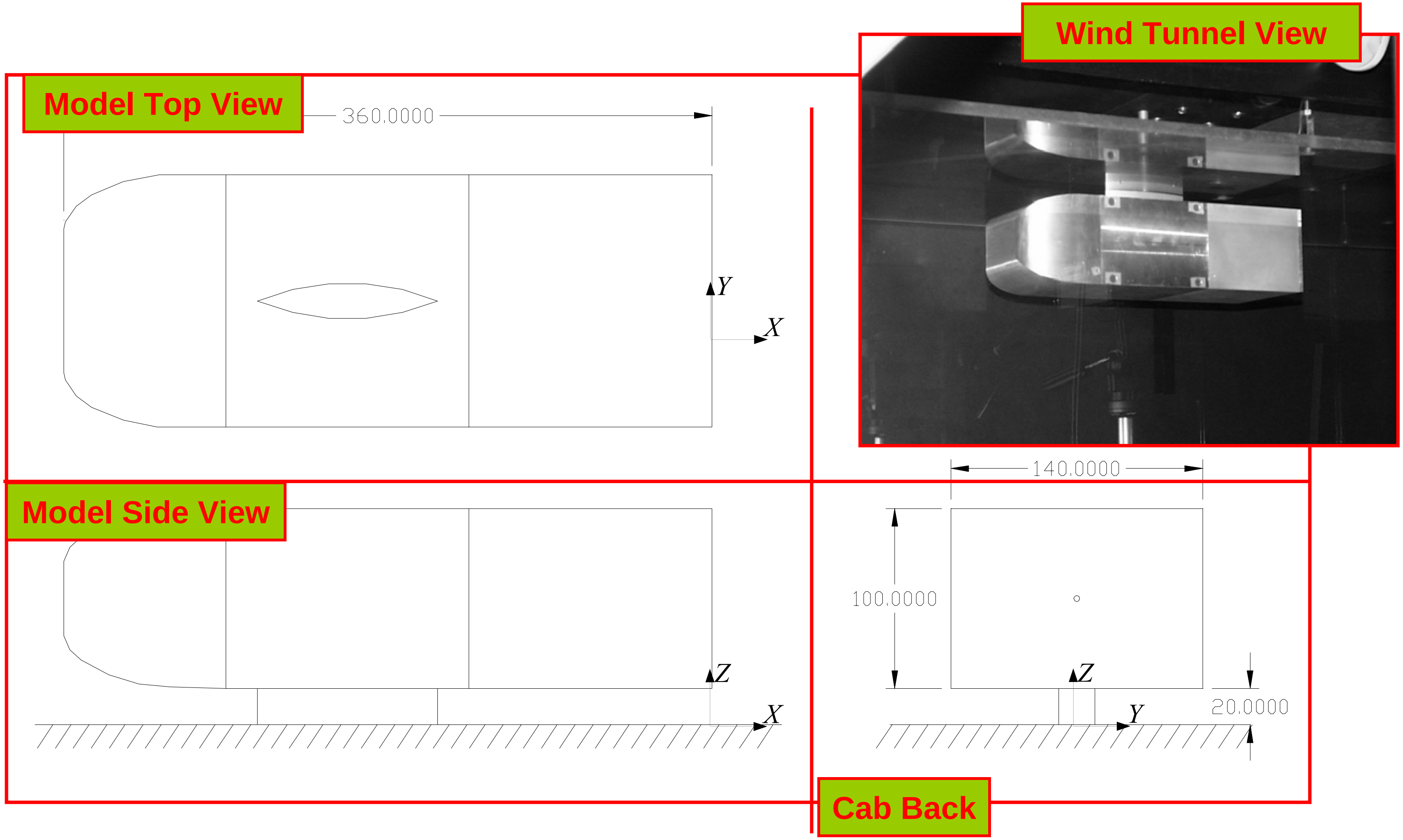


Streamlined body- small wake



Bluff body- large wake

Bluff body:
Square Back (SB) Model



PIV Results